Fashion Applications for Polyester Fiber, Particularly Hydrophilic Polyester

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Overview

Despite the fact that polyester fiber is extremely hydrophobic, it has a bright future, particularly in the fashion industry, as consumers increasingly are attracted by its easy-care properties. While research continues to develop an ideal hydrophilic polyester solution, this article examines ways to increase the hydrophilicity of polyester via processing routes (such as denier reduction and microfibers) and chemical routes (topical finishes).

Introduction

Polyester is a manufactured fiber in which the fiber-forming substance is any long-chain, synthetic polymer composed of at least 85% of an ester of a substituted aromatic carboxylic acid. This can include, but is not restricted to, substituted terephtalic units, p(-R-O-CO-C_6H_4CO-O-$)_x$ and parasubstituted hydroxy-benzoate units, $_p$(-R-O-CO-C_6H_4-O-$)_{x.}$ [12]

Polyester is manufactured by reacting ethylene glycol with either terephtalic acid or its methyl ester in the presence of an antimony catalyst. The reaction is carried out in an autoclave at high temperature (ca 300ºC) for five to eight hours. Then, it placed under a hard vacuum to achieve the high molecular weights required to form useful fibers. Following that, polyester is melt-spun, which involves melting the polymer chips for extrusion through the spinneret and then directly solidifying them by cooling. The filaments are drawn and stretched by about 400% in order to achieve the required characteristics. [12, 13]

History of polyester

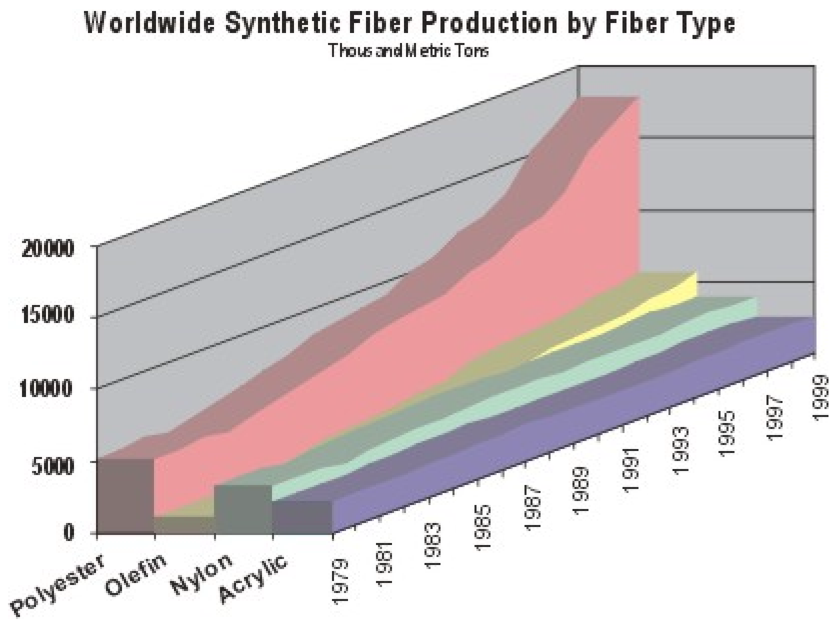
The work of Wallace Carothers in the late 1920s laid the foundation for all processes used in the production of filaments such as polyester. In the late 1940s, Calico Printers Association in Great Britain picked up on Carothers' work and they were the first to produce polyester. DuPont subsequently acquired the polyester filament production patent rights for the United States and ICI acquired the patent rights for the rest of the world.

Polyester was commercialized in the 1950s transforming the "wash and wear" novelty into a revolution in textile product performance. As polyester garments emerged from the dryer wrinkle-free, consumers increasingly bought more garments made from polyester.

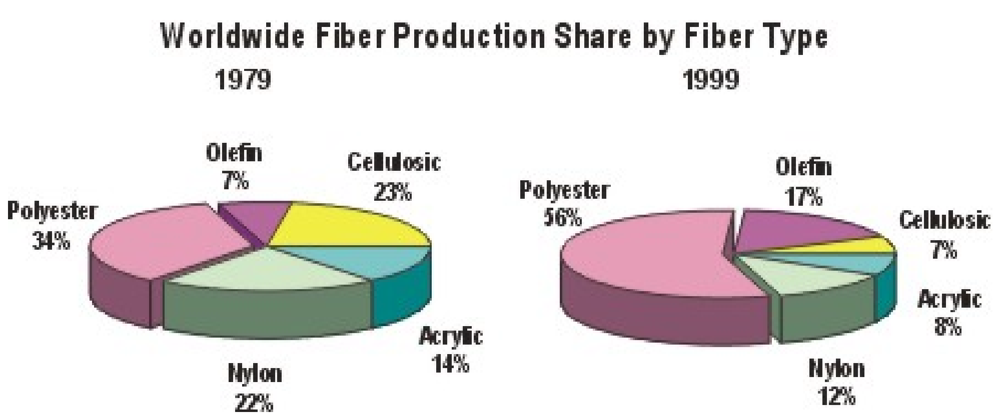
Fabrics became more durable, color became more permanent, and shape-retaining knits offered new dimensions in comfort.

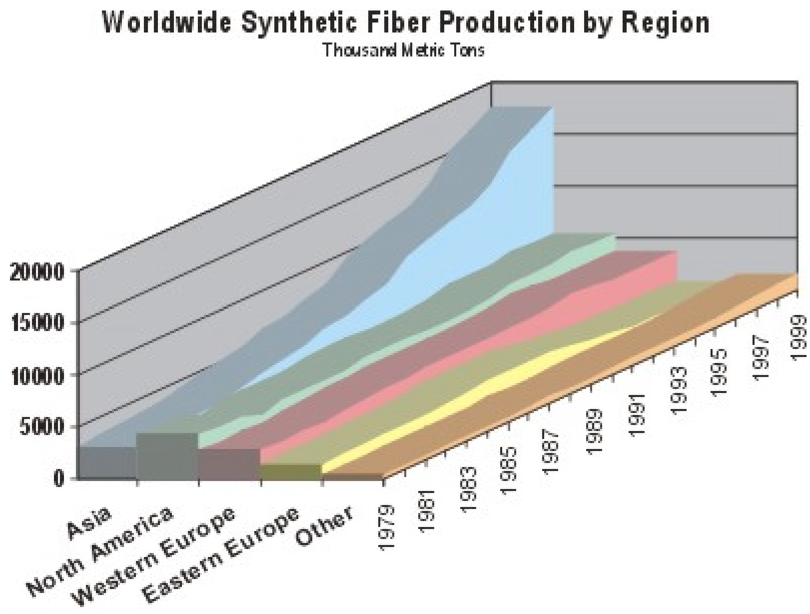
Polyester: The synthetic fiber of choice

According to recent statistics,[12] polyester is rapidly becoming the synthetic fiber of choice with a strong, long-term growth outlook In 1999, statistics show that out of 34.2 million metric tons of synthetic fibers manufactured, 17.9 million metric tons of that amount included manufactured polyester fibers.



In the global synthetic fiber production market, polyester production shares have increased from 34% in 1979 to 56% in 1999. This growth has resulted in a major shift in production from North America and Europe to Asia. In 1999, Asian production was 17.7 million metric tons compared with 5.5 million metric tons in North America and 3.9 million metric tons in Europe.





The need for hydrophilic polyester

Polyester has become very successful within the fashion industry due to its chemical resistance, its wrinkle resistance and its quick-drying properties. However, polyester only has a moisture regain of 0.4% (measured at 20ºC and 65% relative humidity) when compared to cotton, which has a moisture regain of ca 7%. This low moisture regain means polyester is extremely hydrophobic. The hydrophobic nature of polyester results in a relatively low level of comfort, as moisture is not absorbed nor drawn away from the skin. This has restricted the use of polyester in such textile applications as sportswear, underwear and bedding. Additionally, due to the hydrophobic nature of polyester, the fabric will exhibit static problems such as cling during wear and difficulty in cutting and sewing.

Creating a hydrophilic polyester to meet market needs has been explored via chemical routes and processing routes. Chemical routes include using a topical finish and processing routes involve using denier reduction and microfibers. Fabric construction can also influence the hydrophilic properties due to mechanisms of moisture transport between fabrics. Moisture can remain in the fiber cross-sections, on the surface of the fibers, in the voids formed within a yarn by a plurality of fiber channels and in the voids caused by yarn crossovers in woven and knitted fabrics. While vapor transfer depends on air permeability independent of fiber type, capillary wicking of liquid water exhibits a high dependency on the hydrophilic degree of the fibers. A minimum moisture regain of 4% is required to activate the wicking mechanism.[4]

While the high-tech outdoor apparel market is eager to obtain and pay for fiber innovation, the more traditional textile industry is reluctant to add cost to an already competitive market. Most textile applications will not require durable hydrophilic properties, as initial “off the shelf” performance is more important. However, sportswear applications require a five-wash minimum durability. This wash durability requirement will also influence the cost structure. However, it should be noted that due to poor rinsing, successive launderings will leave some residual rewetting surfactants or will erode the surface of the polyester.

Processing route: Denier reduction and microfiber

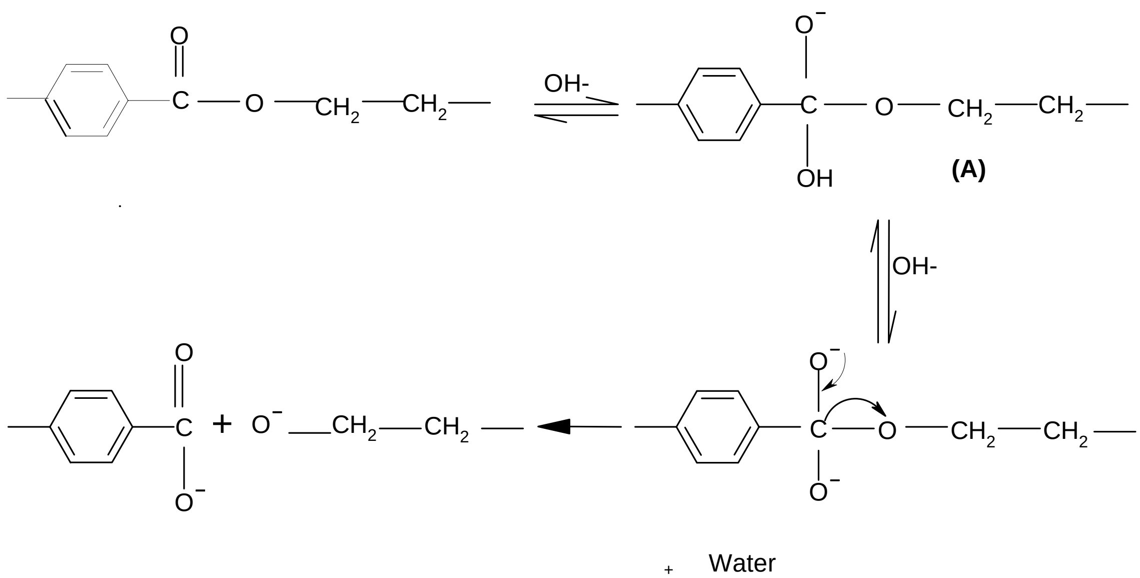
There are ways to increase the hydrophilicity of polyester via processing routes such as denier reduction and microfibers.

Conventional fibers are in the range of 1.5 to 4 deniers per filament (dpf). (For example, cotton contains 1.5 dpf; polyester, contains 2 dpf.) Microfibers are in the range of 0.5 dpf (minimum below 1 dpf) and are manufactured like standard fibers, via extrusion. Microfibers contain up to four times as many filaments as conventional fibers and therefore have more surface area.[8] To illustrate, a woven cloth with a 1 dpf per warp and 0.55 dpf per weft, will have an absorbency of 8 seconds. This considerably improves the hydrophilicity compared with standard fibers and the hand of microfibers is similar to the hand of silk.

Denier reduction is actually an alkalization of the polyester and a surface phenomenon by which shorter chains from the fiber surface are hydrolyzed.[2] It is suggested the number of hydrophilic groups on the fiber surface is increased due to the chain scission. [5]

Denier reduction involves weight loss that varies depending on the initial thickness of the fabric and the bath conditions. Denier reduction of 5% to 15% usually is required in order to achieve noticeable hydrophilicity.

The polyester alkalization mechanism is as follows:[2]



The chemistry, based on the nucleophilic attack of a base on the electron-deficient carbonyl carbon along the polymer chain, causes scissions at the ester linkages and produces carboxyl and hydroxyl polar groups. The increased surface polarity enables polar interaction of hydrogen bonding with water molecules, thus increasing the water wettability of the fibers.

It is the removal of water that drives the reaction to completion. The intermediate anion (A) is negatively charged and due to the electrostatic repulsion, between the negative fixed ions on the polyester and the mobile hydroxyl ions, the further attack by the base will be retarded

The reaction can be processed using three mechanisms: 1) in a solvent at room temperature; 2) in water at high temperature; and 3) in water at high temperature with a cationic catalyst.

When processing via a solvent mechanism, solvents typically used are methanol or ethanol. When methanol is used as the solvent, optimum conditions for the reaction are 5% sodium hydroxide in 20% methanol at 60ºC for 60 minutes. This gives a weight loss of 5%.[1] When ethanol is the solvent of choice, it has been observed that the rubbing fastness of pigments is increased.[7] The concentration of sodium hydroxide required will decrease with the increasing temperature.

Quaternary ammonium salts are usually used as the cationic catalyst when the reaction occurs in water at high temperatures.[6] The positively charged quaternary ammonium ions shield the negatively charged free group in the polyester, therefore facilitating further attack by hydroxyl ions. Because there is a lag time before the activity is appreciable, it is likely that the OH ions are absorbed first by the fiber and that the attachment of the positively charged cationic ions is lower due to their bulky nature.[7]

When working at high temperatures, it is best to raise the temperature very gradually, at a rate of 1º to 2ºC per minute, in order to avoid the appearance of cracks.

Utilizing a processing route to increase polyester hydrophilicity can be accomplished by using a batch process, a semi-continuous process or a continuous process.

A batch process involves utilizing equipment such as jigs, winch beck jets or overflow systems. The duration of the reaction can be calculated on the basis of the denier, caustic soda concentration, bath ratio and temperature. However, the calculation can be imprecise as it also is necessary to take into account not only the fiber type but the heat treatment history as well. Generally, an increase in weight loss is proportional to the concentration of sodium hydroxide.

In a semi-continuous process, the fabric is impregnated with caustic soda at a relatively high temperature prior to rinsing. There are two types of semi-continuous processes – pad batch process and pad roll process. The pad batch process entails the fabric being padded with 20-30% sodium hydroxide and then left to age for 12 to 24 hours at a temperature between 25º and 60ºC. Utilizing the pad roll process, the fabric is padded with 10-20g/L of sodium hydroxide and left to age at 100ºC in a microwave steam chamber.

A continuous process involves impregnating the fabric with caustic soda and then leaving it in either saturated or super heated steam at 105º-110ºC. Debaca™ is one such continuous process developed by Montefibre and Sperotto SPA.[6] In a continuous process, weight loss also increases with alkali concentration, but eventually will reach a plateau.

Denier reduction is used widely, but it is difficult to accurately control the weight loss. Typical levels are 15-30% weight loss. The main reason for not achieving higher levels of weight loss is due to the decrease in the mechanical properties of the polyester fibers. Some research reports a loss of 20% in fiber strength and elongation.[2]

Research is being undertaken on new ways to achieve denier reduction without impacting the mechanical properties of the polyester fibers. One study reports the use of lipase[10] as a more environmentally compatible process because enzymes, generated from renewable resources, are biodegradable. Another paper reports a co-polymerization of acrylamide and diallyldimethyl ammonium chloride on the surface of the polyester.[11]

Chemical route: Topical finish

Another way of increasing the hydrophilicity of polyester is via a topical finish or chemical route. This implies the use of chemicals applied via padding. Fluorinated derivatives[4] are used widely as they exhibit anti-static and soil-release properties, therefore combining several "easy care" properties.

Another chemical route concept is to use a two-part molecule.[3] One part of the molecule will go into the polyester structure like a disperse dye and will confer durability. The other molecular part will be a highly hydrophilic chain. Typical technologies are silicone polyethers and organic quats.

Although topical finishes will confer instant wetting, they generally lack durability and softness.

Summary

Polyester is a growing fiber for textile applications, particularly in the fashion industry. The future of polyester appears bright as more and more consumers are attracted by its easy care properties. While the use of polyester is still restricted in some applications because of its low moisture regain, this is being addressed via denier reduction or topical finishes.

An ideal hydrophilic polyester solution has not yet been developed. Denier reduction can generate a substantial amount of waste, perhaps up to 30% polyester in effluent, and it lowers the mechanical properties of polyester. Microfibers are attractive as they combine properties such as hydrophilicity and a silk-like hand, however their applications are restricted to lightweight garments such as blouses. Topical finishes offer instant wetting but generally lack in durability and softness, and therefore require the use of additional softener. Lastly, solution costs also need to be considered. Although a cost can be offset by high-tech applications, traditional segments like fashion are more price-sensitive.

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